

Language and simulation in conceptual processing

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13.1 Introduction

Theories of cognition often assume that a single type of representation underlies knowledge. Traditionally, most theories have assumed that amodal symbols provide uniform knowledge representation (e.g., Collins and Loftus 1975; Fodor 1975; Newell and Simon 1972; Pylyshyn 1984). More recently, theories have adopted statistical representations (e.g., McClelland *et al.* 1986; O'Reilly and Munakata, 2000; Rumelhart *et al.* 1986). Most recently, theories have proposed that knowledge is grounded in modal simulations, embodiments, and situations (e.g., Allport 1985; Barsalou 1999, 2008a; Damasio 1989; Glenberg 1997; Martin 2001, 2007; Thompson-Schill 2003), while other theories have proposed that knowledge is grounded in linguistic context-vectors (e.g., Burgess and Lund 1997; Landauer and Dumais 1997).

Our theme in this chapter is that multiple systems—not just one—represent knowledge. We focus on two sources of knowledge that we believe have strong empirical support: linguistic forms in the brain's language systems, and situated simulations in the brain's modal systems. Although we focus on these two sources of knowledge, we do not exclude the possibility that other types are important as well. In particular, we believe that statistical representations play central roles throughout the brain, and that they underlie linguistic forms and situated simulations. At this point, we are somewhat skeptical that completely amodal representations exist in the brain, for both theoretical and empirical reasons (Barsalou 1999, 2008a; Simmons and Barsalou, 2003), but we are open to compelling arguments otherwise.

We begin by reviewing linguistic and modal approaches to the representation of knowledge. We then propose the *language and situated simulation (LASS) theory* as a preliminary framework for integrating these approaches. We then turn to empirical evidence for the LASS theory, including evidence for *dual code theory* (Paivio 1971, 1986), evidence for Glaser's (1992) revision of dual code theory (the *lexical hypothesis*), evidence from our laboratory, and evidence from other laboratories. Finally, we address future issues that research from the LASS perspective could address.

13.2 Linguistically-motivated representations of knowledge

Traditional theories of amodal symbols are closely related to language (e.g., Collins and Loftus 1975; Fodor 1975; Newell and Simon 1972; Pylyshyn 1984). Although these theories typically assume that the amodal symbols underlying knowledge differ from linguistic forms (e.g., words), close correspondences exist. Predicates that represent object, property, and event concepts in amodal theories often hold a rough one-to-one correspondence with words that refer to them. For example, the predicates *bird(X)*, *red(X)*, and *buy(X,Y)* represent concepts that correspond roughly to the words 'bird,' 'red,' and 'buy'.¹ Similarly, the propositional representations constructed to represent the meanings of sentences and texts conform closely to their linguistic forms (e.g., Kintsch and van Dijk 1978; van Dijk and Kintsch 1983). For example, the propositional structure *sing(Elizabeth,aria)* corresponds to the sentence, 'Elizabeth sings the aria.'

As these examples illustrate, amodal approaches to representing knowledge are grounded in language. Although these approaches assume that amodal symbols differ from linguistic forms, they adopt an approach to knowledge representation that mirrors language structure.

13.2.1 Theories of linguistic context

More recently, researchers have argued that linguistic forms per se represent knowledge (e.g., Burgess and Lund 1997; Landauer and Dumais 1997). According to this approach, there is no underlying system of amodal symbols that correspond to language – there are only linguistic forms (i.e., words). The intriguing proposal is that statistical distributions of linguistic forms represent knowledge. For example, the representation of *bird* is not an amodal symbol but is instead the distribution of words that co-occur with 'bird' in natural language. According to this approach, two concepts become increasingly similar as their distributions of co-occurring words become increasingly similar.

Thus, this approach to representing knowledge is even more linguistic than traditional amodal approaches. Rather than linguistically-inspired symbols representing knowledge, linguistic forms themselves represent knowledge.

13.2.2 Situated simulation

A very different and much older account assumes that knowledge is grounded in the brain's modal systems. Philosophical theories from ancient philosophers to later empiricist and nativist philosophers assumed that images of experience play central roles in knowledge representation (Barsalou 1999, 2008a; Prinz 2002). Only in the 20th Century have linguistically-inspired theories dominated, especially since the cognitive revolution, when the computer metaphor transformed theories of cognition.

¹ Italics will be used to indicate concepts, and quotes will be used to indicate linguistic forms (words, sentences). Thus, *bird* indicates a concept, and 'bird' indicates the corresponding word.

In recent times, these older theories have been reinvented in the modern contexts of cognitive science (e.g., Barsalou 1999, 2003a, 2005a; Glenberg 1997) and neuroscience (e.g., Allport 1985; Damasio 1989; Pulvermüller 1999; Simmons and Barsalou 2003). According to these theories, the brain captures modal states during perception, action, and introspection, and then later simulates these states to represent knowledge. On perceiving dogs, for example, the brain captures modal states in the visual, auditory, and somatosensory systems about how dogs look, sound, and feel, respectively. On interacting with dogs, the brain similarly captures modal states in the motor and proprioceptive systems about appropriate actions. During these interactions, the brain also captures introspective states associated with affect and mental operations. On later occasions, when representing knowledge about dogs, the brain attempts to reactivate these multimodal states, typically only succeeding partially. The resultant simulation of the brain states associated with experiencing dogs can then be used for a wide variety of purposes, including inference, recollection, language, and thought.

Much empirical evidence has accumulated for this view across disciplines. Reviews of supporting evidence from cognitive psychology can be found in Barsalou (2003b, 2008), Barsalou, Simmons *et al.* (2003), and Pecher and Zwaan (2005). Reviews of results from cognitive neuroscience can be found in Martin (2001, 2007) and Thompson-Schill (2003). Reviews of results from social psychology can be found in Barsalou, Niedenthal *et al.* (2003) and Niedenthal *et al.* (2005). Reviews of developmental evidence can be found in Thelen (2000) and Smith and Gasser (2005). In general, much evidence exists that modal representations play central roles in the knowledge that pervades cognition.

A related theme is that knowledge representations are situated. Rather than being abstract and detached, knowledge about something is simulated in the context of likely background situations. Instead of simulating knowledge in a vacuum, people simulate it in the context of relevant settings, actions, events, and introspections. For example, knowledge about chairs might be simulated in the context of a kitchen, with someone sitting in a chair, feeling comfortable. The presence of situational information prepares agents for situated action. Rather than only representing the focal knowledge of interest, as in a dictionary or encyclopaedia entry, a category representation prepares agents for interacting effectively with its members.

Much evidence documents the importance of situational information in the representation and processing of knowledge. Furthermore, much of this evidence indicates that simulations in the respective modal systems represent situational information. For reviews, see Barsalou (2003b, 2005b, 2008a, *in press*), Barsalou, Niedenthal *et al.* (2003), and Yeh and Barsalou (2006).

13.3 The LASS theory of conceptual processing

Research on knowledge typically focuses on categories of things in the world and on concepts in the cognitive system that represent them (for a broad review, see Murphy 2002). Rather than representing knowledge as holistic images (as a camera does), humans use a powerful attentional system to focus on components of multimodal experience and form concepts that represent knowledge about them. As people focus

attention on objects, properties, settings, actions, events, mental states, affect, relations, etc., concepts develop over time to represent the corresponding categories of exemplars experienced. After focusing attention on robins, for example, a concept develops to represent this category. Focusing attention on hands, valleys, waving, storms, hopes, etc., similarly produces concepts of these categories.

The theme of this chapter is that the representation and processing of concepts relies heavily on both language and situated simulation. The linguistic representations that we believe important are linguistic forms, as in theories of linguistic context, not amodal symbols. In general, we assume that linguistic forms and situated simulations interact continuously in varying mixtures to produce conceptual processing.

Given that most research has addressed conceptual processing when words are presented as stimuli, we focus on word-based tasks. In our opinion, however, research has suffered considerably from an over-reliance on words. We suspect that the conceptual system evolved primarily to process nonlinguistic stimuli, including perceptual, motor, and introspective aspects of experience. We further suspect that the processing of experience continues to be more central in human cognition than the processing of words. At later points, we address implications of the LASS framework for processing experience. Nevertheless, because most research has focused on words, we focus our treatment here on them. In the following sections, we address four aspects of the LASS framework: (1) linguistic processing, (2) situated simulation, (3) mixtures and interactions of language and situated simulation, and (4) the statistical underpinnings of language and situated simulation.

13.3.1 Linguistic processing

We assume that when a word is perceived, the linguistic system becomes engaged immediately to categorize the linguistic form (which could be auditory, visual, tactile, etc.). As Figure 13.1 illustrates, we assume that the linguistic system and the simulation system both become active initially, but that activation for the word form peaks before activation

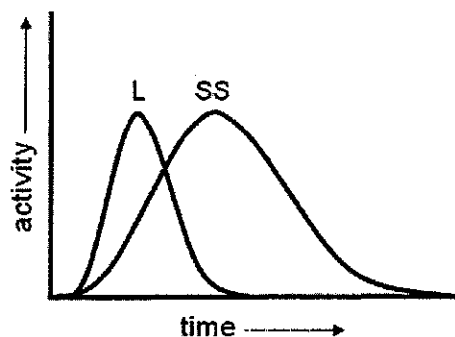


Fig. 13.1 Initial contributions from the linguistic system (L) and the situated simulation system (SS) during conceptual processing. When the cue is a word, contributions from the linguistic system precede those from the simulation system. The height, width, shape, and offset of the two distributions are not assumed to be fixed. In response to different words in different task contexts, all these parameters are expected to change (e.g., SS activity could be more intense than L activity). Thus, the two distributions in this figure illustrate one of infinitely many different forms that activations of the L and SS systems could take.

for the simulation. Following the content addressability and encoding specificity principles, we assume that information in memory most similar to the cue becomes active most rapidly (e.g., Tulving and Thomson, 1973). Because representations of linguistic forms are more similar to presented words than are simulations of experience, representations of linguistic forms peak first.

Once the word has been recognized, we assume that associated linguistic forms are generated as inferences, and as pointers to associated conceptual information. In many of the experiments to follow, the generation of linguistic forms is realized as the simple process of word association, where a cue word elicits other words associated with it (e.g., 'cat' elicits 'fur,' 'purr,' and 'pet'). As we will see, word association plays a central role in the early stages of conceptual processing when words are presented as cues. We hasten to add that word association is the simplest possible form of the linguistic processing that occurs during conceptual processing. Much more complex processing occurs, as compounds, phrases, and syntactic structures are generated and processed.

Once associated linguistic forms are generated, they support a variety of superficial strategies (e.g., Glaser 1992). As we will see later, associations between words can be sufficient to produce correct responses on conceptual tasks – use of deeper conceptual information is not necessary (Kan *et al.* 2003; Solomon and Barsalou 2004). Consistent with linguistic context theory (e.g., Burgess and Lund 1997; Landauer and Dumais 1997), we assume that samples of associated words are generated that provide linguistic context for the presented word. Once a sample becomes active, it supports a wide variety of tasks and implements many basic effects.²

We assume that these linguistic strategies are relatively superficial (following Glaser 1992). Rather than providing deep conceptual information, these strategies provide shallow heuristics that make correct performance easily possible. When the retrieval of linguistic forms and associated statistical information is sufficient for adequate performance, no retrieval of deeper conceptual information is necessary.

Much work on lexical processing is consistent with this proposal. In the lexical decision task, activation of a word's meaning is shallow when read in the context of nonwords that lack acceptable phonology and orthography. Because discriminating words from nonwords can be based on linguistic form alone, there is no need to access and consider meaning. Conversely, when nonwords satisfy rules of phonology and orthography, words access meaning more deeply. Because linguistic form no longer discriminates words from nonwords, meaning must be retrieved to verify that a stimulus is a word (e.g., James, 1975; Joordens and Becker, 1997; Shulman and Davidson, 1977; Stone and Van Orden, 1993; Yap, Balota, Cortese, and Watson, 2006). Similarly, the depth of processing literature

² It is important to note, however, that it is not always clear whether linguistic contexts cause these effects or are merely correlated with them. Because linguistic contexts are correlated with conceptual information, such as the information contained in situated simulations, apparent effects of linguistic context could actually be due to correlated conceptual information. More work is needed to resolve this issue. A likely possibility – the one pursued here – is that both factors contribute to conceptual processing effects.

shows that phonemic orienting tasks produce relatively less activation of meaning than semantic orienting tasks (e.g., Craik 2002; Craik and Lockhart 1972; Craik and Tulving 1975; Lockhart 2002; Morris *et al.* 1977). Broadly speaking, many findings are consistent with the proposal that linguistic forms can be processed superficially.

By no means does superficial processing imply lack of utility. As described later, superficial linguistic strategies can often be highly effective in producing accurate performance, similar to the heuristic value of many other superficial strategies (Gigerenzer 2000). Nevertheless, attributing more conceptual depth to these heuristics than actually exists may mischaracterize them and obscure other important mechanisms that provide deeper conceptual processing.

We further realize that proponents of linguistic and amodal theories are likely to disagree strongly with our claim that purely linguistic processing is superficial. Such theorists are likely to believe instead that the language system contains semantic content and produces deep conceptual understanding. Resolution of this issue depends on further empirical evidence. If future empirical evidence indicates that the linguistic system contains its own semantics, our position will need revision.

13.3.2 Situated simulation

As the linguistic system begins to recognize the presented word, the word immediately begins to activate associated simulations. Linguistic forms associated with the presented word also become active and may begin to activate simulations as well. Thus, activated linguistic forms serve as pointers to simulations that are potentially useful for representing the cue word's meaning. As described earlier, we assume that these simulations tend to be situated, preparing agents for situated action. Specifically, correlated information in perceptual, motor, and introspective brain areas becomes active to represent the concept in a likely situation. We also assume that these simulations are often activated automatically and quickly (e.g., within 200 milliseconds of word onset; Pulvermüller *et al.* 2005; Pulvermüller, Chapter 6, this volume).

Although simulations may become active quickly, they may not dominate conscious deliberate cognition immediately. If executive processing selects a processing strategy that utilizes another system, that system may control behaviour initially. As we will see later, executive processing can focus on the linguistic system as its primary source of information for at least several seconds, before simulations begin to have effects on behaviour. One possibility is that executive processes focus attention on the linguistic system as a source of information for producing responses until this system stops being useful. At that point, executive processes shift attention to the simulation system as an alternative source of information. Notably, simulations are likely to be activated simultaneously while the executive system is producing responses from the linguistic system. This account reconciles the fast access of simulations that Pulvermüller reports with our later findings that the linguistic system can dominate processing for several seconds. We return to this issue when presenting evidence from a functional magnetic resonance imaging (fMRI) study that assessed the production of conceptual information from the linguistic and simulation systems.

Finally, we assume that simulations represent deep conceptual information, unlike linguistic representations, which we view as more superficial. Specifically, we assume that conceptual content about properties and relations resides in simulations. We further assume that basic symbolic processes such as predication, conceptual combination, and recursion, result from operations on simulations. Barsalou (1999, 2003a, 2005a) describes how simulation mechanisms can implement symbolic operations. Barsalou (2008b), reviews relevant evidence. We assume that linguistic forms are not capable of implementing these operations in the absence of simulations. Attempting to perform symbolic operations on linguistic forms alone would be like manipulating symbols in an unfamiliar language, with no true comprehension (Searle 1980). Because simulations provide the meanings of linguistic forms, they are required for implementing symbolic operations. As we will see later, human participants cannot perform the symbolic operation of predication on linguistic forms alone (Solomon and Barsalou 2004). Only when simulations are constructed do such operations become possible. We hasten to add that linguistic forms almost certainly play central roles in symbolic operations as well. As suggested later, symbolic operations probably operate most effectively when both linguistic forms and simulations contribute.

13.3.3 Mixtures and interactions of language and situated simulation

We assume that different mixtures of the two systems underlie a wide variety of tasks. When superficial linguistic processing is sufficient to support adequate task performance, processing may rely mostly on the linguistic system and little on simulation (Glaser 1992; Kan *et al.* 2003; Solomon and Barsalou 2004). Conversely, when linguistic processing is unable to support adequate performance, the simulation system must be consulted for the required conceptual information. Depending on task conditions, conceptual processing may mostly consist of linguistic processing or simulation. Under many conditions, both may contribute equally. We assume that both processes are typically engaged to some extent. As described later, simulation appears to become the dominant processing strategy, at least initially, when non-linguistic stimuli are processed.

When linguistic processing occurs in mixtures, we do not assume that the two systems operate independently. Instead we assume that extensive interactions occur between them. As linguistic forms become active initially, they activate simulations. Once a simulation becomes active, words that refer to its space-time regions become active. As these words become active, they activate simulators that interpret these regions conceptually. Following Barsalou (1999, 2003a, 2005a), we assume that simulators are roughly equivalent to concepts in traditional theories of knowledge.

We further assume that complex linguistic interactions arise from the interplay of these two systems. When a speaker has something to say, for example, a simulation represents it initially (e.g., a speaker simulating anticipated enjoyment while hearing a concert later that evening). Putting the simulation into words requires control of attention across the simulation. When attention focuses on a region, a simulator categorizes it. Linguistic forms associated with the simulator, such as words and syntactic

structures, become active, which are then integrated into the evolving motor program for an utterance (e.g., the speaker stating, 'I'm looking forward to the concert this evening'). In turn, when a listener comprehends the utterance, its words and syntactic structures function as cues to assemble a simulation compositionally that should, ideally, correspond to the speaker's simulation (e.g., simulating the speaker's anticipated enjoyment at the concert).

In reasoning, we assume that similar interactions occur extensively. As people try to figure things out during decision making, planning, and problem solving, they simultaneously engage in simulating the relevant situation and verbalizing about it (e.g., deciding whether it would be better to answer email or review a paper during a 2-hour break between meetings). Whereas simulations represent the content of thought, words provide tools for indexing and manipulating this content, as possibilities are evaluated and decisions made.

In general, we assume that linguistic forms provide a powerful means of indexing simulations (via simulators), and for manipulating simulations in language and thought. As the two systems interact, one may dominate momentarily, followed by the other, perhaps cycling many times, with both systems being active simultaneously at many points.

13.3.4 Statistical underpinnings of language and situated simulation

We further assume that both systems are exquisitely sensitive to the statistical structure of their respective domains. In the simulation system, simulators capture the statistical frequencies of properties and the relations between them in experience. In the linguistic system, it is well established that the frequency of words, the associations between them, and their relations to syntactic structures are coded statistically.

We further assume that the statistical structures in the two systems roughly mirror each other (cf. Louwerse and Jeuniaux, Chapter 15, this volume). One reason is that people constantly hear language that corresponds to perceived situations. As a result, frequencies and correlations in perceived situations are mirrored in frequencies and correlations of words used to describe them. Similarly, when people use language to describe non-present situations, statistical correspondences occur between the situated simulations in memory and the linguistic forms used. As a result of these correspondences, statistical information in each system mirrors experience and each other. For this reason, each system can be useful in providing relevant statistical information under appropriate task conditions. We assume that neural architecture naturally stores extensive amounts of statistical information in this manner.

13.3.5 Caveats about the 'linguistic' and 'simulation' systems

Discussion of the LASS theory so far has assumed simplifications of the 'linguistic' and 'simulation' systems that must be qualified. First, we do not mean to imply that these are modular systems. Clearly, each system is highly complex and draws on many systems distributed throughout the brain. Furthermore, many of these systems probably

contribute to other processes besides language and simulation (e.g., the vision and motor systems contribute to perception and action, respectively, not just to language).

Second, we do not mean to imply that each system takes the same rigid form in every situation. To the contrary, we assume that each system is dynamical such that it draws on different configurations of processes in different situations (Barsalou, Breazeal *et al.* 2007). Furthermore, we do not assume that there is only a single form of simulation in the brain. To the contrary, we believe that the brain implements diverse forms of simulation across different cognitive processes (Barsalou 2008a).

Third, when we refer to the linguistic system here, we are referring to the system that processes linguistic forms, not to the system that represents linguistic meaning. As described earlier, we assume that meaning is largely represented in the simulation system. Clearly in other contexts, the linguistic system would include the representation of meaning, thereby including the simulation system. Because we wish to contrast linguistic forms and linguistic meaning here, we use the 'linguistic system' for the former and 'simulation system' for the latter.

In summary, we use 'linguistic system' and 'simulation system' as simplifications so that we can focus on mechanisms of interest, in particular, linguistic forms versus situated simulations. This usage, however, should not be taken as a commitment to rigid modular systems, nor to the view that the linguistic system is unrelated to the simulation system.

13.4 Previous Evidence Consistent with the LASS theory

We turn to empirical evidence for the LASS theory, beginning with evidence for two related views: Paivio's (1971, 1986) dual code theory, and Glaser's (1992) lexical hypothesis, an extension of dual code theory. We then turn to recent findings from our own laboratory, and conclude with potentially relevant findings from other laboratories.

13.4.1 Paivio's dual code theory

Dual code theory and LASS have much in common. Both assume two basic systems (among others), one linguistic and the other grounded in modalities. Both assume that the two processes underlie a broad spectrum of cognitive activities. Both assume that the two processes operate interactively in different mixtures across different task conditions. Many other deep similarities exist between the two approaches.

Differences exist as well. Whereas LASS assumes that the simulation system performs slower and deeper conceptual processing than does the linguistic system, dual code theory assumes that deep conceptual processing occurs in both systems. Whereas LASS assumes that the simulation system is central to the representation of abstract concepts, dual code theory assumes that the linguistic system is central. In general, LASS places less computational power in the linguistic system than does dual code theory and more in the simulation system.

Over the past 40 years, dual code theory has generated an impressive body of empirical support (for reviews see Paivio 1971, 1986). Much evidence indicates compellingly that cognition relies on two systems, one that processes linguistic representations, and another that processes modal representations. Evidence for two systems

has accumulated in developmental psychology, where modal systems develop faster than the linguistic system. Evidence for two systems has accrued in the individual differences literature, with different individuals relying more on one system than the other. Evidence for two systems has accrued in the literatures addressing episodic memory, semantic memory, and language comprehension. Because of the substantial empirical support that dual code theory has accumulated, the central assumption of LASS that cognition relies on the constant interplay between a linguistic system and a simulation system appears on solid ground.

13.4.2 Glaser's lexical hypothesis

Glaser (1992) reviewed evidence consistent with the view that the linguistic system has less computational power than the simulation system. Glaser starts with dual code theory and modifies it in two ways. First, consistent with the theoretical Zeitgeist of the time, he considers the possibility that Paivio's imagery system might be better viewed as a conceptual system that contains amodal representations. As we will see, however, the evidence that Glaser reviews suggests that his conceptual system might actually be populated with modal representations, not amodal ones (he often appears to approach this conclusion himself). Second, Glaser modifies dual code theory by proposing that the linguistic system can perform relatively superficial processing independently of the conceptual system—what he calls the 'lexical hypothesis'.

Glaser adopts the lexical hypothesis based on findings across many literatures. On the one hand, he addresses the ability of pictures vs. words to access the conceptual system during verification tasks. On the other hand, he addresses the ability of pictures versus words to produce conceptual effects in priming and interference tasks. Each set of studies is addressed in turn.

In verification tasks, pictures are faster than words in accessing the conceptual system. When verifying whether something belongs to a category (e.g., *living things* versus *artefacts*), pictures are verified as category members faster than the corresponding words (e.g., a picture of a cat versus the word 'cat'). This finding suggests to Glaser that pictures provide the fastest access to the conceptual system. It further suggests that the conceptual system may have a perceptual character, rather than an amodal one. Additionally, Glaser concludes that words access the linguistic system first – not the conceptual system – which explains why they take longer to verify than pictures. This latter assumption is a key component of the lexical hypothesis: words can bypass the conceptual system and be processed solely by the linguistic system.

Pictures also produce stronger conceptual effects on priming and interference tasks than do words. In priming tasks, picture primes tend to produce priming effects that are two to three times as large as those produced by word primes. In a representative task, one concept appears as a prime (e.g., *chair*) for a target concept (e.g., *table*), whose superordinate must be produced (e.g., *furniture*). When the prime and target are both pictures (e.g., pictures of a chair and table), priming effects are much larger than when they are both words (e.g., 'chair' and 'table'). The analogous pattern occurs in interference tasks. In a representative task, one concept (e.g., *table*) appears as a target to be categorized (e.g., into

the superordinate *furniture*), but is immediately followed by a distracter that belongs to a different superordinate (e.g., *horse* from *mammals*). When the target and distracter are both pictures, interference effects are much larger than when they are both words.

Glaser explains larger conceptual effects for pictures than for words in the same way that he explains the faster access of pictures to the conceptual system. Pictures access the conceptual system directly, perhaps because of its perceptual character. As a result of this direct access, large priming and interference effects result, given that relations between concepts in the conceptual system are retrieved, producing these effects.

Conversely, words bypass the conceptual system initially, such that the conceptual relations responsible for priming and interference are not retrieved. If the conceptual system is accessed occasionally, or becomes slightly activated, this could produce the small priming and interference effects observed for words. Alternatively, statistical relations between words that mirror conceptual relations between the respective concepts could be responsible, as suggested earlier (evidence for this mechanism will also be provided later when reviewing Solomon and Barsalou 2004). Both mechanisms could contribute to priming and interference effects for words. Conceptual effects could be relatively weak for words either because the conceptual system is accessed occasionally, and/or because statistical relations in the linguistic system tend to be weaker than conceptual relations in the conceptual system.

Glaser's revision of dual code theory with the lexical hypothesis yields an account that is highly similar to the LASS theory. Both assume that there is a linguistic system and a conceptual system. Both assume that the linguistic system performs relatively superficial processing, whereas the conceptual system performs deeper processing. Both assume that superficial linguistic processing can be sufficient under certain conditions for adequate task performance. The primary difference is that Glaser is less inclined than we are to view the conceptual system as containing modal representations, even though he leans in that direction on many occasions when noting the powerful ability of pictures to access conceptual knowledge.

13.5 Evidence for mixtures of two systems in conceptual processing

We next turn to evidence for the LASS theory from our laboratory. We begin with evidence for the presence of two systems – language and simulation – in conceptual processing, and show that the linguistic system tends to provide information before the simulation system. We review evidence from three lines of research: (1) word association and property generation, (2) property verification, and (3) abstract concepts. In all these experiments, we focus on conceptual processing in response to words. As Glaser's review suggested, however, conceptual processing to pictures may operate quite differently.

13.5.1 Word Association and Property Generation

In a series of experiments (Santos *et al.* 2008), participants received a word for a concept and generated related information verbally. In experiment 1, participants generated word associates. In experiment 2, participants generated properties typically true of a concept's instances. In both experiments, LASS predicts that the linguistic system and the simulation system should both contribute to the responses that participants produce verbally

over the course of conceptual processing. Initially, the earliest responses should come from the linguistic system (Figure 13.1). As the simulation system becomes increasingly active, however, responses should increasingly be produced from it as well. Thus, we predicted that the responses produced in both tasks would reflect mixtures of responses from the two systems, with the first responses tending to come from the linguistic system. We also predicted that the linguistic system would contribute a larger amount of information in the word association task than in the property generation task, given that word association focuses attention on the linguistic system.

Word association

In Experiment 1, participants received a word on each trial and were asked to generate associated words (Santos *et al.* 2008). Specifically, participants were asked, 'For the following word, what other words come to mind immediately?' The experimenter recorded the participant's responses on tape. Typically, participants produced 1–3 responses in less than 5 seconds for each cue word. As soon as the participant paused, the experimenter ended the trial. Thus, the experiment aimed to capture the dominant word associates associated with the cue. Each participant produced word associates to 16 cues, drawn from a larger set of 64 cues. The 64 cues referred to highly diverse concepts, including objects (e.g., *car*, *bee*), actions (e.g., *throw*, *calculate*), abstract concepts (e.g., *self*, *fashion*), properties (e.g., *good*, *heavy*), and proper names (e.g., *Jupiter*, *Nike*).

All responses to a given cue word across participants were merged into a single master list, with minor lexical variants combined into a single response (e.g., 'flower' and 'flowers'). As described next, two judges then coded all responses in the master list using a hierarchical coding scheme applied sequentially.

If a response was linguistically related to the cue, it was automatically coded as a linguistically-related response. Consideration of other possible coding categories proceeded no further. For example, the response 'hive' to the cue 'bee' was coded as a linguistically-related response, because 'bee-hive' is a common compound phrase. Participants could have generated 'hive' in response to 'bee' after 'bee' activated the compound linguistic form, 'bee hive,' in the lexical system, which in turn produced 'hive' as a response. Possible linguistic responses included forward compound continuations (e.g., 'bee' → 'hive'), backward compound continuations (e.g., 'bee' → 'honey' from 'honey-bee'), synonyms (e.g., 'car' → 'automobile'), antonyms (e.g., 'good' → 'bad'), root similarity (e.g., 'self' → 'selfish'), and sound similarity (e.g., 'bumpy' → 'lumpy').³ In each case, some type of linguistic relation could have related the cue and response.

If a response did not fall into one of these linguistic response categories, it was then evaluated for being a taxonomic response (e.g., 'dog' → 'animal'). If a response was taxonomically related (but not linguistically related), it was automatically coded as such. Consideration of other possible coding categories proceeded no further. Taxonomic responses included superordinate categories (e.g., 'dog' → 'animal'), coordinate categories (e.g., 'dog' → 'cat'), and subordinate categories (e.g., 'dog' → 'terrier').

³ The syntax of the examples shown here is 'cue' → 'response'.

If a response did not fall into either a linguistic or taxonomic coding category, it was automatically coded as an object–situation response. Interestingly, every valid response that was not a linguistic or taxonomic response, always described either a property of the cue concept or a thematic associate of the cue concept that could co-occur with it in a situation. For example, ‘bee’ produced *bee* properties (e.g., ‘wings’) and situational associates (e.g., ‘flowers’). Similarly, ‘golf’ produced *golf* properties (e.g., ‘boring’) and situational associates (e.g., ‘sunshine’).

The LASS theory makes predictions about the three general coding categories during the word association task. First, LASS predicts that linguistically-related responses should tend to come from the linguistic system. As described earlier, the response ‘hive’ to the cue ‘bee’ could result from ‘bee’ activating the compound linguistic form, ‘bee-hive,’ in the lexical system, which in turn produces ‘hive’ as a response. Importantly, however, ‘hive’ could also result from describing a simulation of a situation containing a bee and a hive. Although this is possible, and probably occurred to some extent, we assume that this possibility is statistically less likely than ‘hive’ originating in the linguistic system. Thus, the prediction is that linguistic responses should be statistically more likely to originate from linguistic processing than from simulation. As a result, linguistic responses should tend to occur early in participants’ protocols, given our assumption that the linguistic system produces responses faster than the simulation system (Figure 13.1).

Conversely, LASS predicts that object–situation responses should be statistically more likely to originate from describing situated simulations than from retrieving linguistic forms. Although the response ‘flowers’ could be associated with ‘bee’ in the linguistic system, we predicted that it would be more likely to arise from the simulation of a situation containing a bee and flowers. In general, we assume that object–situation responses are statistically more likely to result from describing simulations than to result from linguistic retrieval. As a result, object–situation responses should tend to occur relatively late in participants’ protocols, given our assumption that simulations become active more slowly than linguistic forms.

The LASS theory’s predictions for taxonomic responses are less clear than its predictions for linguistic and object–situation responses. On the one hand, taxonomic categories are generally viewed as residing in conceptual systems. On the other hand, people memorize phrases for taxonomic relations during childhood, such as ‘a dog is an animal.’ Thus, taxonomic responses could result from retrieving linguistic forms. Furthermore, it is not clear how taxonomic categories are realized in simulations. How is the superordinate *animal* evident in a situated simulation of a dog? *Animal* is not a concrete property of a dog that is simulated, nor is it a thematic associate that co-occurs with dogs in situations. These observations suggest that taxonomic responses such as ‘animal’ could largely originate in the linguistic system (especially superordinates). As we will see in experiment 2, coordinates and subordinates may often occur as thematic associates in situated simulations (e.g., a simulation of a dog chasing a cat, or of a dog simulated as a collie).

The results of experiment 1 supported the LASS theory. Linguistically-related responses were produced significantly earlier than object–situation responses. Responses that were more likely to originate in the linguistic system occurred earlier than responses that were

more likely to originate in the simulation system. Taxonomic responses fell halfway in between, significantly later than linguistic responses, and significantly earlier than object–situation responses. This suggests that taxonomic responses were sometimes retrieved as memorized lexical phrases, but on other occasions described the content of simulations.

Property generation

Experiment 2 from Santos *et al.* (2008) offered similar evidence using the property generation task. Of the 64 concepts from the word association experiment, 60 were used and, were again highly diverse. Each participant received 30 of the 60 concepts and had to generate typical properties of each. For example, participants were asked, ‘What characteristics are typically true of dogs?’ Participants typically produced 6–7 responses to each cue in the 15-second period allowed for responding. As in experiment 1, participants produced responses verbally, and responses were coded sequentially into the same linguistic, taxonomic, and object–situation coding categories.

One prediction was that participants would produce fewer linguistic responses and more object–situation responses than in the word association experiment. Because the task is more conceptual in nature, and because participants produced responses for longer periods, more responses should originate in the simulation system. This prediction was strongly confirmed. A second prediction was that, again, linguistic responses should precede object–situation responses. As described earlier, linguistic responses should tend to originate in the faster linguistic system, whereas object–situation responses should tend to originate in the slower simulation system. Again, the results confirmed this prediction. Consistent with the LASS theory, linguistic responses occurred significantly earlier than object–situation responses.

Taxonomic responses did not differ from linguistic responses overall, with both tending to be produced early. Importantly, however, different kinds of taxonomic responses varied considerably in how early they occurred. Superordinates were one of the earliest type of responses produced, occurring earlier than all but one type of linguistic response. This finding suggests that superordinates may often be stored linguistically and be generated from the linguistic system. In contrast, coordinates and subordinates were as slow as object–situation responses. This finding suggests that participants may have been simulating coordinates and subordinates in situations, such that these taxonomic categories were reported at the same time as other situational content.

In summary, experiments 1 and 2 from Santos *et al.* (2008) confirmed predictions of the LASS theory: linguistic responses tended to occur earlier than object–situation responses in both experiments, consistent with the theory’s assumptions that responses are produced from a faster linguistic system and a slower simulation system.

Property generation with fMRI

Simmons *et al.* (2008) performed experiment 2 from Santos *et al.* (2008) in a 3-Tesla fMRI scanner. Each participant was scanned twice. In the first scanning session, participants received 30 of the 60 concepts from Santos *et al.*’s experiment 2. As the word for each concept was presented visually, participants generated the typical properties of the

concept to themselves for 15 seconds. Participants practiced generating properties for other concepts out loud outside the scanner before the scanning session, so that covert generation would be similar to overt generation.

In a second scanning session a week later, participants performed two localizer tasks that allowed us to test the LASS theory's predictions about conceptual processing. Participants received the other 30 concepts from Santos *et al.*'s Experiment 2 that they had not received in the first session. For 24 of these concepts, participants were asked to generate word associates for 5 seconds each. For the other six concepts, participants were asked to spontaneously imagine a situation that contained the concept for 15 seconds each (e.g., for *bee*, a participant might imagine a garden with a bee buzzing around a flower, a hive with bees in it, etc.). Concepts were counterbalanced so that each concept occurred in all three generation conditions (i.e., property generation, word association, situation simulation), with a given participant receiving each concept once. Participants received concepts for all three conditions in a blocked design.

Our predictions for the two localizer tasks were as follows. First, we predicted that the word association task would primarily activate left-hemisphere language areas, especially Broca's area. Second, we predicted that the situation simulation task would activate bilateral posterior areas that are typically involved in the generation of mental imagery. Our predictions for conceptual processing during the critical property generation task were as follows. First, we predicted that conceptual processing would contain activations found in both localizer tasks. Second, we predicted that activations found in the word association localizer would occur earlier than activations found in the situation localizer.

Panel A of Figure 13.2 illustrates these predictions. As can be seen, we assume that both linguistic processing and simulation begin immediately. Linguistic processing, however, peaks during the first half of the generation period, whereas simulation processing peaks in the second half. We further assume that the executive system focuses initially on information in the linguistic system, because linguistic information becomes available initially (due to encoding specificity) and/or because verbal responses are requested. As responses from the linguistic system decrease, the executive system then turns to the simulation system as a source of responses. Consequently, the linguistic system is more active during the first half of the generation than during the second, where the simulation system is more active during the second half. Because the executive system extends the activity of each system in time, using it as a source of responses, differences in the processing activity during the two halves are large enough for fMRI to detect (given its relatively low temporal resolution).

Second, consider an alternative account that the linguistic and simulation systems operate fully in parallel from the onset of the cue word, with properties being generated at equal rates from both (Figure 13.2, panel B). If this account is correct, then linguistic processing activity should not be greater in the first 7.5-second generation period than in the second 7.5-second period, and simulation activity should also not differ between the two periods. Note that the predictions in panel B also hold for an additional account that only one system – not two – generates properties. If only one system generates properties, then early versus late processing should not be differentially associated with brain activations that reflect language versus simulation.

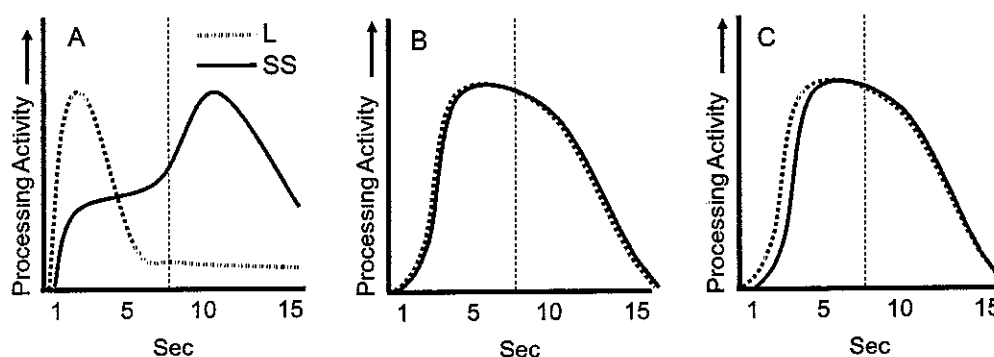


Fig. 13.2 Possible predictions for contributions from the linguistic system (L) and the situated simulation system (SS) during the 15-second property generation periods in Simmons *et al.* (2008). *Panel A:* predictions for the view that the executive system primarily produces responses from the L system for the first 7.5 seconds of the production period and then produces responses from the SS system for the second 7.5-second period. *Panel B:* Predictions for the view that the L and SS systems operate completely in parallel (and also for the view that only one system – not two – produces properties). *Panel C:* Predictions for the view that contributions from the L system only precede contributions from the SS system by about one second or so. The height, width, shape, and offset of the two distributions are not assumed to be fixed. In response to different words in different task contexts, all these parameters are expected to change (e.g., SS activity could be more intense than L activity). Thus, the distributions in this figure illustrate one of infinitely many different forms that activations of the L and SS systems could take.

Finally, consider another alternative account that the linguistic system produces more properties for the first second or so, but that both systems produce properties at equal rates for the remainder of the 15-second period (Figure 13.2, panel C). If this account is correct, then again linguistic processing should not be greater in the first 7.5-second period than in the second. Although simulation does not start quite as early as in panel A, the difference in simulation activity across the two periods should also probably not differ (given the low temporal resolution of fMRI). If there were a significant difference in simulation, this account still predicts no difference for linguistic processing across the two periods.

Turning to the results, first consider activation in the localizer tasks for word association and situated simulation. Activations during these two tasks occurred in the expected areas. Areas that were more active for the word association localizer than for the situation localizer included a large activation in left inferior frontal gyrus (Broca's area), along with large activations in left inferior temporal gyrus, and right cerebellum. All of these areas have been reported previously in research on word processing, especially word generation. Areas that were more active for the situation localizer than for the word association localizer included a large activation in the precuneus, along with a large activation in right middle temporal gyrus. An area in right middle frontal gyrus was also active, but at a lower significance level. These areas are generally not associated with linguistic processing. The precuneus, in particular, is associated with the generation of mental imagery.

Of interest was whether the patterns of activity in the property generation task conformed to the predictions in panel A of Figure 13.2. If so, then the pattern of activation for the word association localizer should have been more active during the first half

of the property period than during the second, whereas the pattern of activation for the situation localizer should have been more active during the second half than during the first. Alternatively, if the linguistic and simulation systems generated properties at equal rates either simultaneously or staggered in time slightly, the patterns of the two localizer tasks should not have been more prevalent in either half of the production period (panels B and C of Figure 13.2).

To test these hypotheses, we divided each 15-second property generation block for a single concept into two smaller 7.5-second blocks for the early versus late phases. We then identified brain areas that were more active in the early phase of property generation than in the late phase, and vice versa. Areas that were more active in the early phase of property generation than in the late phase included left inferior frontal gyrus and right cerebellum. A conjunction analysis showed that these activations lay directly within the same areas observed in the word association localizer. Thus, the linguistic system appeared responsible for responses produced during the early phase of property generation. Areas that were more active in the late phase of property generation included precuneus and right middle temporal gyrus. A conjunction analysis showed that these activations lay directly within the same areas observed in the situation localizer. Thus, the simulation system appeared responsible for responses produced during the late phase of property generation.

Because this experiment used a blocked design, assessing the detailed time course of activation in these brain areas was not possible. An important goal for future research is to assess these time courses in greater detail using event-related fMRI designs, and using imaging techniques that have higher temporal resolution (electroencephalography, magnetoencephalography). Nevertheless, these large predicted differences in activation over a 15-second interval provide strong evidence for the LASS theory. If responses from the linguistic system are not produced for an extended duration first, followed by responses from the simulation system for an extended duration, we would have not have observed different activations in the two 7.5-second periods that fell within the localizer activations. The fact that we observed such large differences in the respective localizer areas suggests that the linguistic and simulation systems make large extended contributions to conceptual processing over long periods of time (panel A of Figure 13.2). Simmons *et al.* (2008) discuss this issue in further detail.

In summary, these fMRI findings corroborate findings from the behavioural experiments in Santos *et al.* (2008). Two systems appear responsible for producing conceptual information: the linguistic system and the simulation system. The linguistic system appears to produce responses earlier than the simulation system. Together, the findings from these three experiments support the LASS theory.

13.5.2 Property verification

We next show that task conditions within a single experiment can modulate the specific mixture of linguistic and simulation information that represents a concept on a given occasion. The experiments described here used the property verification task. On a given trial, participants first received an object name on a computer screen (e.g., 'horse'),

and then verified whether a subsequently presented property was a *part* of the respective object (e.g., 'mane'). Of interest were the times to verify properties, and the accuracy of doing so.

Solomon and Barsalou (2004) proposed that participants can verify properties using either of the two LASS systems. When task conditions allow, participants use a superficial linguistic strategy (following Glaser 1992). When deeper conceptual processing is required, however, participants use simulation. Each approach to verifying properties is addressed in turn.

Linguistic strategy

What conditions might lead participants to adopt a superficial linguistic strategy when verifying properties? Solomon and Barsalou (2004) proposed that participants adopt this strategy spontaneously when information in the linguistic system is sufficient for adequate task performance. One situation where linguistic information is sufficient occurs when the words for the true properties are related to the words for target objects, and when the words for false properties are unrelated to the words for their target objects. For example, the words for the following true object–property pairs are all related: 'bathtub–drain,' 'beaver–teeth,' 'elephant–tusk,' 'sailboat–mast,' 'taxi–meter,' and 'watermelon–seed.' Conversely, the words for the following false object–property pairs are all unrelated: 'pliers–river,' 'airplane–cake,' 'bus–fruit,' 'asparagus–furniture,' 'briefcase–wick,' and 'lion–wire.'

When participants receive true and false pairs like these, they can rely solely on the linguistic system for statistical information that is sufficient for adequate task performance. As described earlier, extensive statistical information resides in the language system, including the associative strength between words. After the object and property words on a trial have been read, participants can simply assess whether they are associated. When the two words are associated, participants respond 'true'; when the two words are not associated, participants respond 'false'. Because linguistic associativeness is highly correlated with correct responses, it can be used to produce correct performance. Importantly, participants need not retrieve any conceptual information. They simply need to detect if the two words are associated, which can be assessed quickly by consulting the linguistic system. Thus, Solomon and Barsalou (2004) predicted that under these task conditions participants would show evidence of using a fast linguistic strategy.

Simulation strategy

Conversely, imagine that a second group of participants receives the same true trials but receives false trials on which the object and property words are related. For example, all the words for the following false object–property pairs are associated (as verified by independent scaling): 'banana–monkey,' 'otter–river,' 'donkey–mule,' 'table–furniture,' 'guitar–keyboard,' 'flashlight–wick.' Note that all of these object–property pairs are false, because the property is not a *part* of the object, which was what participants were asked to verify. Because the properties on these trials were not parts of their respective objects, participants had to respond 'false'.

When participants receive true and false pairs like these, they cannot rely on the linguistic system, because superficial information about word associativeness is not sufficient for adequate task performance. Because both true and false properties are associated with their respective objects, statistical information about word associativeness from the linguistic system is not diagnostic for correct responding. Instead, participants must retrieve conceptual information that specifies whether the property is a part of the object. A *part relation* linking the object and property concepts must be found.⁴

Solomon and Barsalou (2004) proposed that simulations provide the requisite information for making these deeper decisions. Based on Solomon and Barsalou (2001), they argued that on reading the object word, participants first simulate the object. Then, on reading the property word, participants simulate the property. Once both simulations are active, participants assess whether the property simulation can be found in the object simulation. If it can, participants respond 'true'; if it cannot, they respond 'false'.

In summary, Solomon and Barsalou (2004) manipulated whether two different groups of participants received 100 false trials in which the object and property words were either unrelated or related. The object and property words were identical in the two conditions but were paired differently to manipulate relatedness. Both groups received the same 100 true trials, mixed randomly with the 100 false trials.

Results

Solomon and Barsalou (2004) obtained evidence that the false-trial manipulation modulated the extent to which participants used the language or simulation system for verifying properties. When the false trials were unrelated, participants drew more heavily on the linguistic system. When the false trials were related, participants drew more heavily on the simulation system.

First, participants were over 100 milliseconds faster to verify the true trials when the false trials were unrelated than when they were related. This is consistent with the LASS prediction that participants used the faster linguistic system first, when associative strength between words was adequate for task performance in the unrelated false-trials condition. When associative strength between words was not adequate in the related false-trials condition, participants had to use the slower simulation system to find the simulated properties in the simulated objects. This finding is consistent with the analogous findings

⁴ As discussed earlier for Santos *et al.* (2008), people may often store linguistic phrases that describe taxonomic relations (e.g., 'dogs are animals'). In principle, people could similarly store linguistic phrases that describe part relations (e.g., 'elephants have tusks'). If so, then manipulating the relatedness of false trials should have no effect, because people could always assess whether a property is a part by simply consulting the linguistic system – it should never be necessary to consult the conceptual system, even when false trials are related. As will be seen, however, the false-trial manipulation has large effects. When related false trials block the superficial linguistic strategy, conceptual knowledge must be consulted to assess whether a property is actually a part. Thus, people do not appear to typically store linguistic phrases for part relations as they do for taxonomic relations, or at least to the same extent, perhaps because verbal part descriptions are encountered less frequently.

in Santos *et al.* (2008) and Simmons *et al.* (2008) that information is available earlier from the linguistic system than from the simulation system when words are presented.

Regression analyses provided evidence for a qualitative shift in verification strategies across the false-trial manipulation. Solomon and Barsalou (2004) scaled objects and properties on a wide variety of variables that could potentially predict variance in reaction times and errors (see Solomon, 1997, for additional details). Whereas some properties were verified quickly and with high accuracy, others were verified slowly and with lower accuracy. Of interest was identifying variables that explained this variance.

Three groups of variables seemed potentially important: linguistic, perceptual, and expectation variables. The linguistic variables included the associative strength from the object words to the property words, the word frequency of the property words, the length of the property words, etc. The perceptual variables included the size of the properties relative to the objects, the salience of the properties, whether the properties are occluded, whether they are handled, etc. The expectation variables included the variability of property forms, whether properties could be separate objects, etc.

When the false trials were unrelated, Solomon and Barsalou (2004) found that the linguistic variables best predicted verification performance. In particular, associative strength from the object word to the property word was the best predictor. As the associative strength between an object word and a property word increased, participants verified properties faster and with higher accuracy. Thus, these participants appeared to be using superficial statistical information from the linguistic system to verify properties. The stronger the associative strength between the concept and property words, the easier it was to verify the properties. Interestingly, as associative strength became weak between two words, participants relied increasingly on the simulation system, as described later.

A different pattern of prediction emerged in the related false-trials condition. The importance of linguistic variables in explaining performance decreased significantly, and the importance of perceptual variables increased significantly. Indeed, perceptual variables became the strongest predictors, with the size of a property being the best predictor. As properties became larger, they took longer to verify and produced more errors. Because larger properties take longer to simulate and to match against a simulated object, verifying them led to longer response times and produced more errors (more errors resulted from participants responding before they had taken sufficient time to simulate the larger properties). Kosslyn *et al.* (1983, 1988) provide related evidence that simulating large objects takes longer than simulating small ones.

Thus, this experiment offers evidence that conceptual processing relies on both language and simulation, as the LASS theory predicts. Under conditions that allowed the use of word associations, participants relied on the linguistic system. When the presence of related false trials blocked this strategy, participants used simulation to assess whether properties were parts of objects.

An additional finding from the unrelated false-trial condition provides evidence that these participants drew on the language and simulation systems dynamically. When participants in the unrelated false-trial condition responded quickly on true trials, the linguistic variables best predicted their performance. When these same participants

responded slowly on true trials, however, their performance was best predicted by the perceptual variables. This pattern suggests that the language and simulation systems were operating in parallel. When a strong linguistic association was readily available between the object and property words, participants used it to respond quickly, given that the false trials were unrelated. Conversely, when a strong linguistic association was not available, participants could not respond on the basis of linguistic information and relied instead on the simulation system. Thus, in the unrelated false trials condition, performance relied dynamically on the two systems, depending on whether the linguistic system could provide the requisite information quickly for using the linguistic strategy.

Notably, definitive information for performing the task came from the simulation system, not from the linguistic system, consistent with the LASS theory. If the linguistic system contained deep conceptual information, then it should have been sufficient to produce the information required for correct decisions even when the false trials were related. If this system contained classic amodal propositions, it should have been unnecessary to access the simulation system. Instead, participants had to shift from the linguistic system to the simulation system to find definitive conceptual information.

Solomon (1997) reports a replication of this experiment using different materials and procedures. Solomon and Barsalou (2001) provide further evidence that participants rely on perceptual information to verify properties when the superficial linguistic strategy is blocked, as do Pecher *et al.* (2003, 2004; for a review, see Barsalou, Pecher *et al.* 2005).

Neural corroboration

Kan *et al.* (2003) performed the Solomon and Barsalou (2004) experiment in an fMRI scanner. They predicted that if the false-trial manipulation had modulated verification strategies in Solomon and Barsalou's experiment, then neural evidence should corroborate this modulation. Specifically, they predicted that when related false trials forced participants to use the simulation strategy, brain areas that process visual images should become active. Conversely, when unrelated false trials allowed participants to use the linguistic strategy, activation in these visual imagery areas should not occur.

Kan *et al.* predicted that the false-trial manipulation should modulate neural activity in the left fusiform gyrus, given that previous research on generating visual images from concrete words activated this area (e.g., D'Esposito *et al.* 1997; Thompson-Schill *et al.* 1999). When participants in those studies generated images of concrete objects from names, left fusiform areas became active, suggesting that these areas should similarly be active when simulating objects and verifying their properties.

Kan *et al.*'s fMRI findings corroborated the behavioural findings of Solomon and Barsalou (2004). When false trials were related, the left fusiform area observed in the previous imagery studies was active. When false trials were unrelated, this area was not active. Like the results of Solomon and Barsalou, this pattern indicates that two systems support conceptual processing. When task conditions allow, participants use linguistic information, such that the simulation system does not play a central role. When task conditions block the use of linguistic information, the simulation system becomes necessary for adequate performance. Again, these results are consistent with the

conclusion that deep conceptual information resides in the simulation system, not in the linguistic system.

13.5.3 Abstract concepts

Based on the finding that memory tends to be better for concrete concepts than for abstract concepts, dual code theory proposed that the linguistic system represents abstract concepts for the following reasons (Paivio 1971, 1986). Because both the linguistic and simulation systems represent concrete concepts (two systems), memory for concrete concepts is good. Because only the linguistic system represents abstract concepts (one system), memory for abstract concepts is inferior. Based on a wide variety of compatible findings, many researchers have since echoed this view. In particular, nearly all neuroimaging researchers who have assessed the neural bases of concrete and abstract concepts have concurred with dual code theory (for a review, see Sabsevitz *et al.* 2005). Because these studies have generally found left-hemisphere language areas more active for abstract than for concrete concepts (especially Broca's area), they, too, have concluded that language represents abstract concepts.

A logical problem with this account is that language *per se* cannot represent a concept. If people use an unfamiliar foreign language to describe the meaning of an abstract concept, they do not understand the concept (cf. Searle 1980). They only understand the concept once they can ground the language in experience. This suggests to us that simulations of situations should be central to the representations of abstract concepts (Barsalou 1999). Evidence for the *context availability theory* of abstract concepts supports this conclusion (Schwanenflugel 1991).

Findings from Barsalou and Wiemer-Hastings (2005) also support this conclusion. When participants generated properties of concrete and abstract concepts, the properties generated for both showed more similarities than differences. For each type of concept, participants tended to describe the situations in which a concept occurred, including relevant information about agents, objects, settings, events, and mental states. Participants produced all these different kinds of properties for both concrete and abstract concepts, and produced them in roughly the same distributions.

Although strong similarities existed between these distributions, differences existed in content and complexity. Regarding content, abstract concepts focused on mental states and events significantly more than concrete concepts, whereas concrete concepts focused more on objects and settings. Regarding complexity, abstract concepts included more information, deeper hierarchical structures, and more contingency relations. Regardless, situations appeared equally important for both abstract and concrete concepts. Rather than only depending on language, abstract concepts appear to include extensive situational information as well (Schwanenflugel 1991). As much work has shown, however, concrete words tend to access situations faster than do abstract concepts, thereby giving concrete concepts an advantage in superficial processing tasks.

Wilson *et al.* (2008) assessed this conclusion further in an fMRI experiment. These researchers argued that previous neuroimaging experiments had only found evidence for linguistic representations of abstract concepts because they used tasks that allowed and

encouraged superficial linguistic processing (e.g., lexical decision, synonym judgments). Because the tasks in these experiments can be performed using information from the lexical system, they did not engage the simulation system that represents deeper conceptual information (Glaser 1992; Solomon and Barsalou 2004; Kan *et al.* 2003).

To engage the simulation system, Wilson *et al.* gave participants the word for an abstract concept for 5 seconds and then had them verify whether the concept applied to a subsequent picture. For example, participants received the word 'convince' and assessed whether the concept *convince* applied to a picture of a politician speaking to a crowd. Wilson *et al.* argued that participants had to activate deep conceptual representations of the abstract concept during the 5-second priming period to determine whether its associated concept applied to the subsequent picture. If so, then areas involved in simulation should become active as participants prime conceptual representations of the abstract concept.

Wilson *et al.* confirmed this prediction. When participants received the abstract concept *convince* and prepared to assess whether it applied to a subsequent picture (across many trials), they activated brain areas involved in representing mental states and social interaction (e.g., medial prefrontal cortex). Similarly, when people prepared to assess whether the abstract concept *arithmetic* applied to a subsequent picture (again across many trials), they activated brain areas involved in performing arithmetic operations (e.g., intraparietal sulcus). For both concepts, participants simulated relevant situations to represent the respective concept prior to receiving a picture. Notably, the linguistic system was not more active for abstract concepts than for concrete concepts under these task conditions.⁵

These results suggest that the representation of abstract concepts can differentially recruit the language and simulation systems. When task conditions allow, as in previous experiments, participants rely only on the language system, because it is adequate for task performance (e.g., in lexical decision and synonym tasks). When task conditions require deeper conceptual processing, participants rely on the simulation system, because it provides the necessary information for performing the task (e.g., verifying that an abstract concept applies to a picture). Similar to Glaser's (1992) conclusion, processing pictures tends to produce deeper conceptual processing. Consistent with findings in previous sections, different mixtures of the language and simulation systems support the processing of abstract concepts under different task conditions.

13.6 Potential relevance of the LASS theory to other phenomena

The previous sections offered direct evidence for the LASS theory. Here we turn to more speculative evidence from a *post hoc* perspective. We next review phenomena where the two LASS systems – language and simulation – could potentially play important roles. We hasten to add, however, that the researchers studying these phenomena typically offered

⁵ In these analyses, only activations for the words were analysed, not activations for the subsequent pictures. Activations for the words and pictures were deconvolved so that activations for word meaning could be examined in isolation.

alternative interpretations of them based on different pairs of systems, not the LASS systems. Nevertheless, we believe that the LASS systems could be part of the story. Although the accounts proposed originally for these phenomena may be correct to some extent, interplay between the language and simulation systems may be important as well. We review the phenomena in this section simply to raise this alternative interpretation. Future research will be necessary to resolve which account is correct. We would not be surprised if multiple accounts, invoking multiple systems, are necessary. In general, however, we suspect that the interplay between language and simulation is a central theme across the spectrum of cognitive activities (again, see Paivio 1971, 1986, for a similar view).

13.6.1 Language comprehension

Much work in language comprehension is consistent with the view that one system processes linguistic forms, whereas another system uses simulation to represent meanings. In classic work, Sachs (1967) showed that surface memory for sentences lasts around 20 seconds and is then replaced by gist representations; much subsequent research confirmed this phenomenon. Typically, surface memory is viewed as residing in working memory, whereas gist is viewed as residing in long-term memory, represented by amodal symbols.

Although the working versus long-term memory distinction is probably an important part of the story, so may be the distinction between language and simulation. Whereas surface memory reflects linguistic structures in the linguistic system, gist memory may reflect simulations in the simulation system. Once the linguistic form of a sentence is lost from working memory, the only information remaining is a simulation in long-term memory. Because this simulation is not linguistic, it does not enable direct recovery of the sentence's linguistic form but is nevertheless consistent with its meaning (i.e., gist).

Based on these findings, Bransford and Franks (1971) further demonstrated that gist memory loses information about the specific form of linguistic input. Bransford and Franks presented participants with a series of sentences about a situation and showed that the meanings of these sentences were integrated into a coherent semantic representation. As a result, participants could no longer remember the actual sentences studied. Instead, the more that a test sentence corresponded to the integrated gist, the more participants believed that they had seen the sentence, even when they had not. Other researchers showed, however, that under various conditions, participants could remember the surface forms of the input sentences (e.g., Katz 1973; Flagg *et al.* 1975). A large literature has continued to develop around this issue (e.g., Brainerd and Reyna 2004).

Again, the distinction between surface form and gist can be aligned with the LASS distinction between language and simulation. Whereas the surface forms of the input sentences are stored in the language system, the integrated gist is stored in the simulation system. As participants hear a sentence sequence, they incrementally construct a simulation to represent the situation being described, losing linguistic forms in the process.

More recent work on comprehension echoes these older themes. McKoon and Ratcliff (1992) argued that when people read texts superficially, they do not compute many inferences that go beyond the linguistic forms mentioned explicitly.

Conversely, Graesser *et al.* (1994) argued that when people process texts deeply, they compute a wide variety of inferences. This distinction between minimal versus rich inference can again be aligned with the language and simulations systems in LASS. When minimal inferencing occurs, people primarily process linguistic forms in the linguistic system. If they construct simulations, they may primarily simulate the meanings of individual words without integrating them into a coherent global simulation – instead, simulations of the individual word meanings are relatively fragmented. Conversely, when rich inferencing occurs, people may perform much more simulation and, in particular, integrate simulations for individual words into a global simulation (as in Bransford and Franks 1971). During the integration process, deep comprehenders may add additional information into the global simulation to make it coherent. As a result of greater integration and coherence, these simulations contain inferences that go considerably beyond words mentioned in the text.

Individual differences in text comprehension can similarly be tied to differential use of the two LASS systems. Poor comprehenders may have to expend so much effort processing linguistic forms that they have minimal capacity left to simulate and integrate word meanings. Because good comprehenders are superior at processing linguistic forms, they spend more time simulating and integrating meaning, and thus exhibit higher comprehension. Van Petten *et al.* (1997) offer evidence for this account. They found that readers with low working memory capacity readily produced linguistic inferences but did not produce meaning inferences. Conversely, readers with high working memory capacity produced both. From the LASS perspective, the poor readers had enough capacity to produce word-level inferences within the linguistic system, but did not have enough capacity to construct rich integrated simulations that represent meaning.

13.6.2 Conceptual processing

Researchers who study concepts have reported related results. Wisniewski and Bassok (1999) found that when participants assess the similarity of two concepts, they inadvertently allow thematic associations to affect their similarity judgements. Participants should have only assessed shared and distinctive properties of the two concepts, ignoring thematic associations between them. For example, when participants judged the similarity of *coffee* and *cup*, they should have only assessed their shared and distinctive properties, ignoring the thematic relation that coffee is drunk from cups. Problematically, however, participants allow thematic relations like these to inflate their similarity judgements.

Gentner and Brem (1999) showed that participants can filter out thematic associations when they receive sufficient time to judge similarity. From the LASS perspective, thematic associations may originate quickly in the linguistic system, similar to the linguistic associations between concepts and properties in Solomon and Barsalou (2004). Conversely, similarity judgements may operate on simulations, as people compare simulations of the two concepts for shared and distinctive properties. When fast responses are possible, thematic information from the linguistic system dominates, and similarity

information from the simulation system has less effect. When participants must take more time, they can suppress thematic responses from the linguistic system and focus attention more on the assessment of simulations.

Chaffin (1997) had participants produce word associates to high- versus low-frequency words. In general, the high frequency words often produced semantic responses that described events. In contrast, the low-frequency words often produced linguistic responses, such as synonyms and sound similarities. Low-frequency words also often produced definitions. According to Chaffin, the high-frequency words produced deeper processing associated with the pragmatics of using these words, whereas the low-frequency words produced shallower processing associated with trying to establish their meanings.

A complementary explanation is that high-frequency words readily activate situated simulations in the simulation system, whereas low-frequency words primarily activate linguistic forms in the language system. High-frequency words are associated with pragmatic information because they activate well established event simulations from experience that support situated action. Low-frequency words are associated with linguistic information because they have not been associated with enough experience to activate familiar situations. As a result, low-frequency words activate synonyms and definitions in the linguistic system, because this is what people have primarily learned about them from hearsay.

13.6.3 Social processes

Smith and DeCoster (2000) proposed that two systems underlie a wide variety of social processes. One system provides fast associative information; the other provides slower rule-based information. On some occasions, social processing results from quickly accessing relatively superficial information that is statistically likely (e.g., stereotypes). On other occasions, social processing results from more thoughtful processing that relies on careful reasoning about particular situations.

Although the distinction between associations versus rules is probably central to these two forms of processing, we suspect that the distinction between the linguistic and simulation systems may be central as well. Following Glaser (1992), we suspect that fast superficial processing in social situations often draws on the linguistic system, with linguistic structures being sufficient for task performance (as in Solomon and Barsalou 2004; Kan *et al.* 2003). Conversely, we suspect that slower, more careful processing often operates on simulations of social situations. Simulating how a social situation developed and how it may evolve over time may often underlie deliberate social reasoning. For a related account, see Barsalou, Niedenthal *et al.* (2003).

13.6.4 Clinical phenomena

A recent study by Schlamann *et al.* (2006) suggests that language and simulation underlie treatments in medical and psychological settings. The authors performed an fMRI study with stroke patients who had undergone therapy to help them simulate helpful motor activity. Interestingly, these patients activated the simulation system when

asked to think about various motor actions. Conversely, control patients who had not received the therapy did not activate the simulation system, suggesting that they processed the motor actions more superficially.

This pattern suggests that patients in medical and psychological settings may vary in how deeply they understand their illnesses and treatments. Whereas some patients may only have superficial understandings of their situations as described in verbal descriptions, other patients may have deeper understandings grounded in simulation (analogous to the earlier distinction between shallow and rich comprehension). If so, then one important question is whether understanding illnesses and treatments in terms of simulations produces better treatment outcomes. If simulation-based understanding improves outcomes, then inducing such understandings in patients could have significant benefits.

13.6.5 Education

The distinction between superficial linguistic comprehension and deep simulation-based comprehension also appears central in education (cf. Glenberg *et al.*, in press). Students may vary widely in how well their understanding of a particular domain engages both the language and simulation systems. Whereas some students may only be able to regurgitate memorized verbal descriptions about a domain, stronger students may be able to manipulate simulations of the domain, thereby having deep insights about it, along with the ability to go beyond explicit instruction. I suspect that seasoned instructors are familiar with both kinds of students.

13.6.6 Summary

As these speculative examples illustrate, the interplay between the language and simulation systems may be pervasive throughout diverse psychological phenomena, as Paivio (1971) noted originally. We suspect that such interplay is likely to occur in many other areas besides those just covered (for many additional examples see Paivio 1986). Again, further research is necessary to explore these possibilities.

13.7 Discussion

We began by proposing that multiple systems – not one – support conceptual processing. In particular, we have focused on contributions from the linguistic and simulation systems. We saw evidence of both in conceptual processing, and we saw that they play different roles in different concepts and in different task contexts. We also saw that deeper conceptual processing requires the simulation system. When the linguistic system dominates, conceptual processing appears to be relatively superficial, consistent with Glaser's (1992) lexical hypothesis.

Although we have focused on the language and simulation systems, we do not mean to preclude contributions from other systems as well. As described earlier, we believe that statistical representations underlie the processing of both language and simulation. Both the frequency of representations in these systems, along with correlations between them, enter ubiquitously into conceptual processing.

An interesting question is whether stand-alone statistical structures can serve representational purposes in the absence of linguistic and modal representations. Some theorists, such as Damasio (1989), have argued that statistical structures primarily serve to trigger modal simulations. Others have suggested that statistical structures can function as stand-alone representations (e.g., Rogers and McClelland 2004). Still others have suggested that statistical structures primarily serve to trigger simulations, but can function as stand-alone representations in automatic stimulus–response sequences (e.g., Simmons and Barsalou 2003). Regardless of where the empirical findings come down on this particular issue, there is no doubt that statistical representations play central roles throughout conceptual processing.

13.7.1 Complex linguistic processing

Much of the work so far that has assessed interactions between the linguistic and simulation systems has assessed relatively simple forms of linguistic processing. In our experiments, we have primarily assessed word association, property generation, and property verification. Furthermore, in Figure 13.1, we only considered a single cycle of interaction between the language and simulation systems. As Figure 13.3 illustrates, however, we assume that much more complex interactions occur. Over time, both systems cycle through periods of relative activity and inactivity as processing evolves. Rather than operating independently, we assume that the two systems are highly interdependent. The activation of linguistic forms activates simulations. In turn, simulations activate words that describe and manipulate them. We assume that these processes cycle interactively over time in myriad patterns.

Following Barsalou (1999, 2003a, 2005a), we assume that the linguistic system plays central roles in producing the compositional structure of simulations. Specifically, we assume that the syntactic structure of sentences controls the retrieval, assembly, and transformation of the componential simulations that people integrate to represent sentences and texts. Similarly, we assume that interactions between the two systems are responsible for the representation of propositions, conceptual combinations,

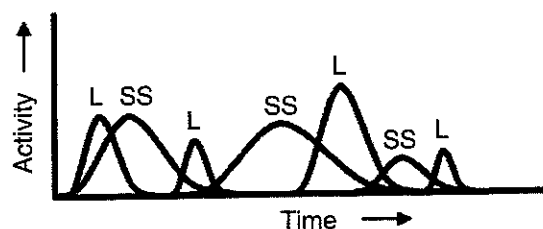


Fig. 13.3 Iterating and interacting contributions between the linguistic system (L) and the situated simulation system (SS) during conceptual processing. When the cue is a word, contributions from the linguistic system precede those from the simulation system. After the initial cycle of processing, both systems cycle through periods of activity and inactivity as they interact with each other. As in Figures 13.1 and 13.2, the height, width, shape, and offset of the distributions are not assumed to be fixed (i.e., the particular distributions in this figure illustrate one of infinitely many different courses that interaction between the L and SS systems could take).

productively produced phrases, recursively embedded structures, etc. In general, we assume that symbolic structures and symbolic operations on these structures emerge from ongoing interactions between the language and simulation systems. In the future, we believe that it will be essential for researchers to explore these more complicated interactions between language and simulation.

Psycholinguistics research increasingly explores these complex interactions. For example, Glenberg and colleagues have explored relations between syntactic structures and the affordances available from simulations (e.g., Glenberg and Roberston 2000; Kaschak and Glenberg 2000). Zwaan and colleagues have explored how sentences activate corresponding simulations and operations on them (Zwaan and Madden 2005), as have de Vega and colleagues (e.g., de Vega *et al.* 2004; de Vega 2005). Other researchers similarly explore complex relations between language and simulation, including Spivey *et al.* (2000), Richardson *et al.* (2003), Matlock (2004), and Richardson and Matlock (in press).

In the future, we believe that it will be increasingly productive to explore detailed relations between compositional linguistic forms and compositional simulations. Theories in cognitive linguistics offer many intriguing ideas about the corresponding compositional structures of language and experience that researchers could explore in rigorous empirical experiments (e.g., Coulson 2000; Fauconnier 1997; Goldberg 1995; Kemmerer 2006; Lakoff 1987; Langacker 1987; Talmy 1983).

13.7.2 Superficial conceptual processing in the linguistic system

According to traditional views, deep conceptual processing results from processing language-like propositional structures, with modal representations playing peripheral roles. As we have seen, however, the opposite may be true. Deep conceptual processing may require the simulation system. When only the linguistic system is engaged, conceptual processing appears relatively superficial (Glaser 1992). As described earlier, Solomon and Barsalou (2004) found that participants could not determine whether a property was a part of an object only using linguistic information (also Kan *et al.* 2003). When word associations did not distinguish true from false trials, participants switched from using the linguistic system to the simulation system. This suggests that processing simulations was required to establish that a property was part of an object. Rather than this relation being stored amodally – ‘*part(X,Y)*’ – or linguistically – ‘object Y has property X’ – this relation appeared to be computed by simulating the property and determining whether it could be found in the simulated object (see Solomon and Barsalou 2001 for further evidence).

Why would the human conceptual system have evolved this way? Why would the linguistic system only provide superficial information relevant to conceptual processing? Why would processing simulations produce deeper conceptual information? Following evolutionary theorists, we believe that the basic architecture of the human conceptual system existed in previous species (e.g., Donald 1993). Specifically, we believe that simulation systems existed long before humans, so that multimodal experience could be captured to inform situated action (e.g., Barsalou 2005b). By storing memories of multimodal experience, these memories could later be simulated to generate anticipatory inferences that supported feeding, reproduction, etc. Language evolved later for

controlling the simulation system to a much greater extent. Adding language increased the ability of the simulation system to represent non-present situations (past, future, counterfactual). Adding language increased the ability to construct simulations compositionally and the ability to coordinate simulations between agents, yielding more powerful forms of social organization.

From this perspective, it is perhaps not surprising that the linguistic system by itself is only capable of superficial conceptual processing. If it primarily serves as a control system for manipulating simulations, then it would be unlikely to contain the most central conceptual information. If it did, it would not be a control system – it would be the main conceptual system (i.e., there would be no need for a simulation system). As we have seen, however, the simulation system appears necessary for deep conceptual processing. Furthermore, its evolutionary precedence suggests that it has had longer to evolve sophisticated mechanisms than the language system.

Most importantly, both systems are probably essential for achieving the powerful symbolic abilities of the human cognitive system. Neither system alone is likely to be sufficient for symbolic behaviour. Indeed, adding a linguistic system to the simulation system almost certainly enhanced symbolic behaviour considerably. Across many abilities, the two systems work together to achieve the power and distinctive properties of human intelligence.

Interestingly, the linguistic system appears to contain considerable amounts of statistical information that mirrors the content of the simulation system, which in turn mirrors the content of experience. As a result, when linguistic cues are received, they initially trigger statistically-related linguistic forms that provide fast heuristic processing. The success of linguistic context theories to explain diverse cognitive phenomena may reflect this use of the linguistic system (e.g., Burgess and Lund 1997; Landauer and Dumais 1997; Louwerse and Jeuniaux, Chapter 15, this volume). Again, however, the ability of the linguistic system to play a heuristic role should probably not be equated with deep conceptual processing (e.g., Glaser 1992; Glenberg and Robertson 2000; Solomon and Barsalou 2004).

13.7.3 The time course of processing simulations

Across the literatures we have reviewed, superficial linguistic processing preceded deep simulation processing temporally. As Pulvermüller and colleagues have found, however, simulations can become activated automatically and quickly, within 200 milliseconds of word onset (Pulvermüller *et al.*, 2005; Pulvermüller, Chapter 6, this volume). As suggested earlier, however, simulations may not dominate executive processing immediately (Figure 13.2, panel A). When the executive system focuses attention on another system as a source of information, this system may control responses, while simulations run unattended in parallel.

Consider the examples reviewed here. In Santos *et al.* (2008), we found that linguistic responses tended to initially dominate word association and property generation for at least a second or two. In Solomon and Barsalou (2004), we found that accessing the simulation system required at least another 100 milliseconds of processing than accessing

the linguistic system. In Simmons *et al.* (2008), we found that language areas dominated the first 7.5 seconds of brain activation.

Why does executive processing select the linguistic system first as a source of relevant information on these tasks? One potential factor is that the cues on all these tasks are words. When participants receive words as cues for conceptual processing, the information available first may be other words, following the principles of content-addressable memory and encoding specificity (e.g., Tulving and Thomson 1973). Furthermore, because participants must respond with words in many of these tasks, this may further orient executive processing towards the linguistic system. When the linguistic system is capable of generating a correct response (as in the unrelated false condition of Solomon and Barsalou 2004), there is no need to go outside this system. When the linguistic system cannot generate responses on its own, however, attention must shift to the simulation system, which takes extra time. Although the simulation system may produce simulations all along, it may only be consulted when necessary.

One important goal for future research is to further document parallel streams of activity in the two systems, along with interactions between them. Another important goal is to articulate the executive processing strategies that draw on these two processing streams. How do executive strategies determine which stream to process under what conditions? When do executive strategies shift attention to a different stream? How do executive strategies make decisions based on the content of the stream(s) processed?

13.7.4 Conceptual processing of nonlinguistic stimuli

Throughout this paper, we have focused on paradigms where words serve as cues for conceptual processing. From the perspective of evolution, however, words have only played this role a very short time – nonlinguistic experiential states have played this role much longer.

Prior to humans, other animals certainly possessed conceptual skills. As they experienced motivational states, such as feeling hungry or thirsty, they recognized these states as instances of familiar concepts (e.g., *hungry*). Similarly, as they experienced sensory states, such as seeing or hearing prey, they recognized these states as indicating the presence of familiar categories in the world (e.g., *deer* for a lion). Clearly, nonhumans do not have linguistic labels for these categories, nor may they experience acts of categorization consciously (although perhaps they do). Nevertheless, a system in the brain that represents the concept identifies instances as category members. Furthermore, once an instance has been bound to a concept, the concept produces conceptual inferences about what is likely to happen next. Once *hungry* has been categorized as an internal state, for example, simulations of hunting and finding prey become active. Once *deer* becomes bound to a perceived object, simulations of attacking and eating become active. In these senses, nonhumans have powerful conceptual systems that evolved to process experience, not words.

Because humans evolved from nonlinguistic species, their conceptual systems, too, are probably heavily oriented toward processing nonlinguistic experience. Indeed, it seems obvious that tremendous amounts of categorization and inference take place as we process events in our bodies and in the world. Furthermore, our ability to consciously

perceive and categorize introspective states may vastly exceed this ability in other species. In particular, greater introspective abilities may be central to the significant presence of abstract concepts in the human conceptual system (Barsalou 1999; Barsalou and Wiemer-Hastings 2005; Wilson *et al.* 2008).

How might conceptual processing differ as a function of receiving sensorimotor and introspective cues instead of receiving word cues? One obvious possibility is that simulations that situate perceived information may precede the activation of linguistic forms. Again, following the principles of content addressability and encoding specificity, experience may activate situated simulations faster than it activates language because simulations are more similar to cue information. Such simulations may provide the myriad situational inferences documented in the literature (e.g., Barsalou 2003b, 2005b, *in press*; Barsalou, Niedenthal *et al.* 2003; Yeh and Barsalou, 2006).

Another likely effect of experiential input to the conceptual system is stronger conceptual effects. As Glaser (1992) found, conceptual priming and interference are both much larger for picture cues than for word cues. Again, this suggests that conceptual information is established most strongly in the simulation system, with corresponding statistical structures in the linguistic system being weaker. This further suggests that deeper understandings of situations occur when people receive experiential input than when they receive linguistic input. Experiential input may be more likely to activate the simulations that carry deep conceptual information about a situation than do words that describe it.

Linguistic structures are also likely to become active in response to experiential input, although they may become active more slowly than simulations. Much remains to be learned about the roles that these linguistic activations play in the conceptualization of experience. One possibility is that the linguistic structures activated by an experience activate simulations that are more distant than the simulations activated by experience itself. Whereas experience may tend to activate simulations that map closely onto it, linguistic structures may tend to activate simulations of situations that are likely to follow the perceived situation (i.e., predictions), or that preceded it (i.e., explanations). Another important function of linguistic activations may be to draw attention towards important regions of experience that are relevant for situated action. As a word becomes active, it may name a region of a simulation and shift attention towards it (e.g., Estes *et al.*, 2008).

In general, we believe that the conceptual processing of experience deserves much greater scientific examination than it has received so far. Researchers typically study words because it is much easier to use words as laboratory stimuli than it is to use pictures, sounds, touches, actions, and introspections. In our opinion, however, this has led to distorted views of cognition, in general, and of the conceptual system, in particular. Clearly, language plays central roles in cognition and conceptualization. Nevertheless, experience plays a role that is at least as central. We hope that researchers increasingly study language and conceptualization in the context of experience. More balanced theories of cognition are likely to result.

Debate

Lawrence Shapiro: First let me say that was, I think, just a great series of experiments. I have some questions about how it ties in with the LSA stuff. I have the impression that you want to say that the word association process could be using some mechanism like LSA and then we move to the situation stuff, which is using some other sort of mechanism. But why can't we assume that LSA explains all of it? And also what kind of reaction-time predictions should LSA be making? As an advocate of LSA I don't think we have to be committed to any sort of reaction-time predictions.

Lawrence Barsalou: Yeah, I see no *a priori* reason why you couldn't try to explain all of these results with an LSA-like mechanism. I think where things get tricky is explaining the effects of factors like the size of properties in property verification, and why you see all these activations in modality-specific areas. Not just in our work, but in many other people's work – Friedemann's and Alex Martin's and others. There's just so much evidence now that these other mechanisms are engaged, it seems likely that they play a role. Now they could be epiphenomenal, as various people have suggested, and maybe there is something like an LSA mechanism that's at the core of everything. I think that's a plausible hypothesis and it's an empirical question which of those views is correct. So much evidence now exists though, some of it causal, that I strongly doubt that simulations are epiphenomenal.

Friedemann Pulvermüller: Thanks very much for an excellent, very interesting talk. Let me comment on a minor thing. You started with Paivio's theory, and I think this is an interesting starting point. However his model was not fully appropriate with regard to brain models; for example, he placed his verbal system in the left hemisphere and the imagery system in the right, which we have argued in the past doesn't work out. The imagery system has to be bihemispheric.

Barsalou: Let me just comment and then I'll let you continue. We're not at all arguing that Paivio's entire theory is totally correct. It's just the spirit of the idea that there are two systems for language and modality-specific processing that are both central to conceptual processing. At many detailed levels I agree with your concerns and have several disagreements with dual coding theory.

Pulvermüller: Let me also say something about the imaging experiment you mentioned towards the end. There were significant differences between the methods of the localizer conditions, for example, in one case there were trials of 5 seconds, in the other case trials of 15 seconds. And then there were many word cues in one condition and only a few word cues in the other. So these are all things that could lead to why you observed more activation in Broca's area in one condition than in the other.

Barsalou: Well, again, let me describe the way that those localizer tasks worked. For both the word association and the situation simulation localizer tasks, there were 15-second blocks and every 5 seconds a visual stimulus appeared in both conditions. In the word association condition, a different word occurred during each of those 5 seconds. And in the situated simulation it was the same word every 5 seconds.

Now, it could be that there is a difference between the same word and a different word. But the concept condition was just like the situated simulation condition – the same word occurred every 5 seconds. If that's what was going on, then the results in the concept condition should have looked more like the situated simulation condition, overall, than like word association at any point. However, the results of the concept condition looked more like word association than like situated simulation early on, and more like situated simulation later. If the minor differences in presentation had been critical, this pattern wouldn't have occurred – the entire concept processing period should have only looked like situation generation. In general, the controls in this experiment were strong; for example, the words were identical in all three conditions. Also, we replicated the results twice.

Pulvermüller: I'm totally happy with your conclusions apart from one, namely that the simulation should be so late, because our data very strongly indicate that the earliest neurophysiological correlates of automatic simulation occur as early as the brain responses we can relate to lexical access – to the word-form processing. But now you might say, well, we are looking only at the first brain responses and what you are perhaps tapping into here are mechanisms that extend later in time. Is this correct?

Barsalou: Yeah, I totally agree. Your results are much more diagnostic on the nature of early activation than ours are for a variety of reasons. I'm totally comfortable with the idea that simulation areas become active immediately. It's an interesting question, though, whether the whole simulation is active initially. My guess is that that takes time, and I think there might be some ERP findings that are consistent with late semantic processing. One reason why I don't think we see, say, activations in the motor area in those first 7.5 seconds is that the semantics of these diverse concepts are probably distributed all over the brain. And one reason we only see, in the second 7.5 seconds, the precuneus and the right temporal area is because the semantics of all these words are so diverse that they're activating very different sorts of modality-specific areas, such that we don't get an aggregation of signal for any particular kind of property, such as motor properties. We assume that activations for these properties are there, but because all concepts don't activate the same properties, not enough aggregation occurs for a BOLD signal to be detected. We suspect the precuneus is involved in generating the situation, as opposed to particular content of the situation. We think if one did this kind of experiment with a very specific kind of concept, e.g., motor terms, you might find activation in those first 7.5 seconds. It would be consistent with what many people have been finding.

Arthur Glenberg: So you noted the relation of your theory to Paivio and to Glaser, but it seemed like there was another obvious relation and that's to construction-integration theory. It seemed really close. I was wondering if you or Walter had anything to say about that.

Barsalou: Absolutely.

Walter Kintsch: This is exciting work but the ideas and processes need a lot of elaboration. It's not just the initial activation of the meaning but that the meanings get elaborated in time, which involves not just linguistic processes but also perceptual simulations. This kind of processing is like what we tried to do with the integration process, yes.

Unidentified person: What about Rips, Shoben, and Smith? I thought the perceptual stuff was supposed to come quickly and that it's the more analytic *is-a* relations that come later. How do you reconcile their model and findings with your approach?

Barsalou: That's a great connection. One of the reasons we got into the false-trial manipulation in semantic memory experiments is because of experiments like theirs, which manipulated false trials as well. I think they're right that there are different phases of processing, but I disagree with the interpretations of what the early versus late phases are doing. I think that the early processing they observed probably reflects word association, not perceptual or semantic representations of characteristic features.

Author note

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